Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 81, Issue 2 (2021) 1-13

Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879

Characteristic of TiO_2-SiO_2 Nanofluid With Water/Ethylene Glycol Mixture for Solar Application

Mohd Amiruddin Fikri[1, 5*], Wan Mohd Faizal[1], Hasyiya Karimah Adli[1], Rizalman Mamat[2], Wan Hamzah Azmi[2], Zafri Azran Abdul Majid[3], Anwar Ilmar Ramadhan[4]

[1] Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, 17600, Malaysia
[2] College of Engineering, Universiti Malaysia Pahang, 26600, Malaysia
[3] Kulliyyah of Health Allied Science, International Islamic University Malaysia, 25200, Malaysia
[4] Faculty of Engineering, Universitas Muhammadiyah Jakarta, 10510, Indonesia
[5] Engineering Division, Jabatan Kesihatan Negeri Kelantan, 15590 Kota Bharu, Kelantan, Malaysia

ARTICLE INFO

Article history:
Received 3 November 2020
Received in revised form 5 February 2021
Accepted 10 February 2021
Available online 21 March 2021

Keywords:
composite nanofluids; water-ethylene glycol; heat transfer; solar radiation

ABSTRACT

Solar energy is a sustainable energy supply technology due to the renewable nature of solar radiation and the ability of solar energy conversion systems to generate greenhouse gas-free heat and electricity during their lifetime. In this study, an experimental investigation was conducted to explore the effect of hybrid nanofluids on heat transfer for solar application. An experiment was conducted for hybrid nanofluid concentrations starting from 0.3, 0.5, 0.7 and 1.0%. Each setup was exposed to short wavelength radiation under a solar simulator with 300, 500 and 700 W/m2 for 30 minutes, of which 15 minutes is the heating period and the next 15 minutes is for cooling. For solar radiation of 300 W/m2 within 15 minutes of charging process are 51.9 °C, 52.8 °C, 53.4 °C and 54.2 °C for concentration of nanofluids 0.3, 0.5, 0.7 and 1.0% respectively. The results for solar radiation of 500 and 700 W/m2 within 15 minutes almost the same pattern which is increasing during the charging process. It can be concluded that the higher concentrations of nanofluid give ample time to the test tube to transfer the heat and thus increased its temperature during the charging process.

1. Introduction

Renewable energy sources are those resources which can be used to produce energy again and again. Renewable energy is the use of renewable sources which includes solar, wind, hydro, biomass, tidal, geothermal, etc. Nowadays renewable energy has been used widely as strong contenders to improve the plight of two billion people, mostly in rural areas, without access to modern forms of energy [1]. It plays an important role in providing energy with sustainability to the vast populations in any developing countries which have no access to clean energy. Development and implementations of renewable energy project in rural areas can create job opportunities and thus

* *Corresponding author.*
E-mail address: moamfik.selehor@gmail.com

https://doi.org/10.37934/arfmts.81.2.113

minimizing migration towards urban areas [2]. Currently, renewable energy sources supply somewhere between 15% and 20% of total world energy demand [3]. The development of a variety of renewable energy technologies available at different stages [4]. Renewable energy technologies are clean sources of energy that have a much lower environmental impact than conventional energy technologies [5]. There are many studies and reviews on the important of renewable energy for future demand [6-16]. Energy services with zero or almost zero emissions of both air pollutants and greenhouse gases can be provided by renewable energy sources that meet domestic energy requirements [17]. The important of renewable energy is not only for the environment in reducing gas emission but also gaining global importance. The development of a renewable energy system will make it possible to resolve the presently most crucial tasks like improving energy supply reliability and organic fuel economy; solving problems of local energy and water supply; increasing the standard of living and level of employment of the local population; ensuring sustainable development of the remote regions in the desert and mountain zones; implementation of the obligations of the countries with regard to fulfilling the international agreements relating to environmental protection [18]. It could be the best option by harvesting the renewable energy in a decentralized manner to meet the rural and small scale energy needs in a reliable, affordable and environmentally sustainable way [19, 20].

Solar energy has the greatest potential of all the sources of renewable energy especially when other sources in the country have depleted and even plays a vital role in providing clean, safe and reliable power. Therefore, many breakthrough researches are currently continuing on solar energy due to the great interest on this potential energy [21-29]. Solar energy is a sustainable energy supply technology due to the renewable nature of solar radiation and the ability of solar energy conversion systems to generate greenhouse gas-free heat and electricity during their life time. Nowadays the government started solar power adoption with subsidies. The solar energy falling on Earths continents is more than 200 times the total annual commercial energy currently being used by humans [30]. The sun emits energy at a rate of 3.8×10^{23}kW, of which, approximately 1.8×10^{14}kW is intercepted by the earth [31]. There are various applications and devices nowadays which used solar energy, and it serves a lot of another benefit to the consumer. One of the benefits is the consumer who installs a solar panel array on the house can sell surplus energy to the local utilities. It is possible to make solar Powered Electricity cost comparable with other types of fuel within the next decade since the solar panel cost reduced to 50% [5]. The utilization of “zero emission” technologies plays a significant role in the reduction of hydrocarbons use and the reduction of $CO2$ emissions.

During the last two decades, the utilization of solar energy has developed considerably in various applications. Solar water heating systems can be classified as the simplest and most widely used solar energy collection and utilization devices. The solar water heater is one of the solar thermal systems which is the most cost-effective renewable energy technologies and has enormous market globally. They are intended to supply hot water for domestic use and are based on natural circulation. The life span of the solar water heater is taken to be 20 years, and the thermal performance degradation of the system is assumed to be 1% per year [32]. There are various studies has done by the researchers to increase the efficiency of the solar water heater [33-35]. Solar water heating systems have increased wide applications in the building sector globally over the past four decades [36]. Most solar water heaters for buildings are flat-plate types or conventional heat pipes array installed on roofs for layout convenience. They consist of a collector, storage tank and connecting pipes which used to supply hot water at a temperature of about 60-degree Celsius [32]. The household sector represents about 70% of total energy use in the building sector, and the biggest part is used for water heating ad space heating. It has been the best solution by employing solar energy to reduce this amount of energy coming from conventional energy sources.

Solar collector plays a significant role in the absorption of solar energy since solar energy is one of the best renewable energy sources with minimal environmental impact. Variety applications have been proposed for the utilization of solar collectors by direct absorption. However, there are many methods to improve the efficiency of these collectors [37]. Several types of solar collector have been used in collecting solar energy. The most common type of solar thermal collector utilizes a black surface as the absorber, which can transfer heat to a fluid running in tubes embedded within or fused onto the surface [38].

The term “nanofluid” was coined by Choi [39]. It refers to a liquid containing a suspension of submicronic solid particles (nanoparticles). The characteristic feature of nanofluids has been observed by Matsuda *et al.,* which is thermal conductivity enhancement than those of conventional pure fluids [40]. Some experimental investigations also have shown that nanofluids have great potential for heat transfer enhancement [41, 42]. Today nanofluid has become an important medium since the applications of this so-called “smart fluids” has become widespread in various improvement.

Hybrid nanofluid can be defined as the composition of two variant types of dispersed nanoparticles in a base fluid. During the increasing research of using nanofluid, recently the researchers have also tried to use hybrid nanofluids, which is engineered by suspending different nanoparticles either in mixture or composite form [43]. The way of the hybridization process contributes to the various properties of hybrid nanofluid. There are many experimental studies conducted on hybrid nanofluid due to various advantages [44-55]. It is showed that to make the hybrid nanofluids to be more promising for heat transfer enhancement, it is important to ensure the hybridization process has appropriately done.

According to Sundar *et al.,* [56], the combination of two or more different nanoparticles in the liquid base is intended for hybrid nanofluids. Higher heat conductivity and lower viscosity than microfluidics are the advantages of using nanofluid in heat transfer applications. There are many studies and reviews have published on the hybrid nanofluids for future investigation [57-59]. Their papers relate to hybrid nanofluid preparation, performance and application methods. Hence, to understand hybrid nanofluid behavior, investigation of thermal conductivity and viscosity is essential in the application of heat transfers.

Thereby, the investigation of thermal conductivity and dynamic viscosity of TiO_2- SiO_2 nanofluids is essential for understanding the heat and performance and physical behavior of nanofluids. There are many experimental studies conducted on hybrid nanofluid due to various advantages [60-62]. Some researchers have been conducting studies on thermal conductivity and dynamic viscosity of the necessary water mixture: ethylene glycol (EG). The results show that several factors have influenced the increase in thermal conductivity; including focus, working temperature, particle size, surface-to-volume ratio of nanoparticles and stability nanofluid [56, 63-65]. The results show that thermal conductivity is mostly increased with the addition of nanoparticles into the base fluid.

Lately, many researchers carry out studies on hybrid nanofluids for thermal conductivity and dynamic viscosity [61, 63, 66]. Baghbanzadeh *et al.,* [67] have presented its working papers on thermal conductivity and dynamic viscosity of SiO_2 / MWCNT nanofluids. The results show that nanofluid concentration increases are essential and it affects the nanofluid hybrid. However, improvements are found to be lowest in high concentrations. Thus, the combination of nanofluid increases with increasing nanofluid concentration is a sufficient thermal conductivity. Performance of heat transfer is important in giving an understanding of its behavior by investigating dynamic viscosity and thermal conductivity of TiO_2- SiO_2 nanofluids. Therefore, the volume concentration of 0.3 to 1.0% has provided for TiO_2- SiO_2 nanofluids with water/EG mixture to obtain the thermal conductivity and dynamic viscosity below 30-70 °C with 10 °C intervals.

The characteristic of TiO_2 and SiO_2 nanoparticles dispersed in a mixture of water/EG are very limited for solar application. Researcher such as Hamid *et al.,* [68] and Nabil *et al.,* [59] were measured TiO_2-SiO_2 nanofluids in water/EG mixture (60:40) with volume concentrations up to 3.0%, and the temperatures range from 30 to 80° C for fundamental heat transfer experiment. Therefore, due to this issue, the present study is carried out by preparation and thermo-physical properties of TiO_2-SiO_2 nanofluids ratio 70:30 in water/EG (60:40) with volume concentrations 0.3, 0.5, 0.7 and 1.0% and the temperatures range from 30-70° C will be tested by varies the value of intensity light starting from 300, 500 and 700 W/m2 respectively.

2. Methodology

2.1 Preparation of Nanofluids

Nanoparticles used in this experiment are Titanium Oxide (TiO_2) and Silicone Oxide (SiO_2). This information is obtained from US Research Nanomaterials, Inc. (USA). For 40 wt. % concentration and size of 30-50 nm for TiO_2 and 25 wt. % concentration and size of 30 nm for SiO_2 in their respective water suspensions. Eq. (1) below is used to change the weight concentration to the volume concentrations while Eq. (2) is used for the preparation of hybrid nanofluids in the range of 0.3, 0.5 and 1.0% concentrations using mixed solvents with a basic liquid [69]. This basic liquid mixture is between water and ethylene glycol at a ratio of 60:40. Mixing process using a mechanical mixer for 30 minutes and undergo a 2-hour sonication process for each concentration provided to improve nanofluid stability [70]. Table 1 shows the properties of TiO_2, SiO_2 nanoparticles, and water / EG.

$$\emptyset = \frac{\omega \rho_{bf}}{\left(1-\frac{\omega}{100}\right)\rho_P + \frac{\omega}{100}\rho_{bf}} \tag{1}$$

$$\varDelta V = (V_2 - V_1) = V_1\left(\frac{\phi_1}{\phi_2} - 1\right) \tag{2}$$

Table 1
Characteristics of TiO_2- SiO_2 nanoparticles and water/EG

Characteristics	TiO_2	SiO_2	Water/EG
Purity (%)	99	99.99	99.5
Color	White	Colorless	Colorless
Size (nm)	30-50	22	-
Concentration (wt %)	40	25	-
Density (kg/m^2)	4230	2220	-

2.2 Thermo-physical Properties

The thermal conductivity of the samples was measured using KD2 Pro thermal property analyzer of Decagon Devices, Inc., USA as shown in Figure 1. The data were collected for a temperature range of 30 to 70 °C after two hours of the sonication process. Various investigators used KD2 pro thermal property analyzer in their measurements of thermal conductivity [71-76]. This instrument applied the transient hot-wire method. The present measurement method allowed the thermal conductivity measurement of nanofluids with minimum free convection effects. The experiment was performed three times for each sample and condition, and a data point reported in this study thus represents an average of three measurements with an estimated error of ±1.7%.

(a) WNB7 Memmert Water Bath (b) Nanofluid Sample (c) Thermal Properties Analyzer

Fig. 1. Apparatus and Instrument used in thermal conductivity measurement

The viscosity of the nanofluids was measured using Brookfield LVDV-III Ultra Rheometer (Figure 2). Several investigators were used Brookfield Rheometer in their measurement of viscosity [77-79]. The viscosity was measured in temperatures between 30 °C and 70 °C and the values were recorded at steady state conditions, and 30 min was allowed to stabilize the temperature.

Fig. 2. LVDV III Ultra Rheometer

2.3 Experimental Setup

To conduct the experimental of solar radiation, the system is designed as in Figure 3. The experimental set up consists of a test tube that is controlled with spotlight dimmer. The intensity light of test tube via spotlight. One thermocouple is entered to the inside of the test tube.

In this paper, different nanofluid effects have been investigated in the scope of solar-heat-absorbing applications - materials for nanofluid properties for solar heat used in experiments. Figure 3 shows the experimental setup with the solar simulator. Experiments were conducted for nanofluid concentrations ranging from 0.3, 0.5, 0.7 and 1.0%. The parameters and properties involved in the experiment are given in Table 2.

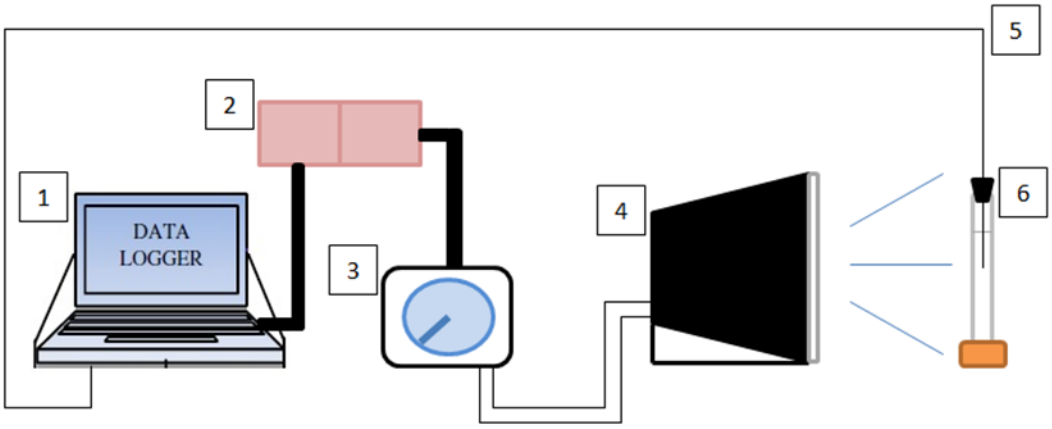


Fig. 3. The solar radiation test rig

Table 2
Detail description of solar radiation test rig

No.	Description	Specification
1	Data logger	ADAM View Advantech Data Acquisition
2	SSO	Switch Socket Outlet (Data Logger & Spotlight Dimmer)
3	Dimmer	Setting up with pyranometer (300, 500 and 700 W/m^2)
4	Spotlight	Halogen 500 W
5	Thermocouple	K-type
6	Test Tube	100 ml

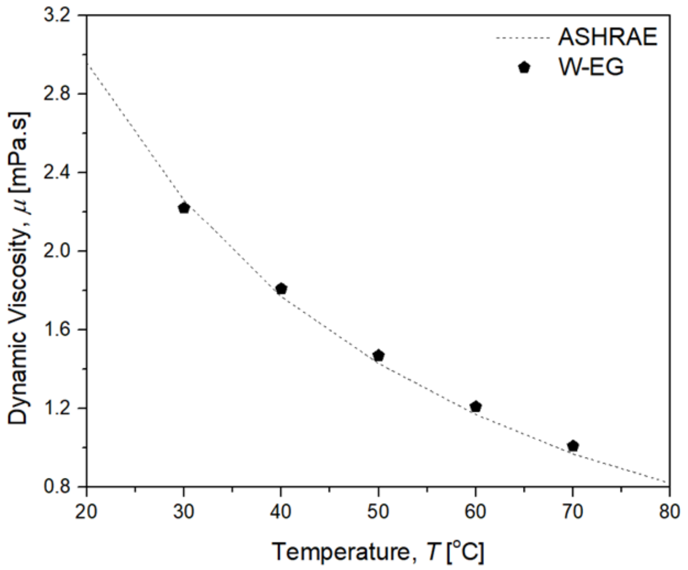
For each concentration, the data in the test tube is collected. The measurement of heat rates on solar simulators was taken using a pyranometer. Each preparation is exposed to short wavelength radiation under the solar simulator with 300, 500 and 700 W/m^2 for 30 minutes, of which 15 minutes is the heating period and the next 15 minutes for cooling. The readings for each parameter were recorded in a two-minute sequence. The experimental procedure is divided into two stages, for the heating and cooling of the test tubes. This is done to determine the rate of radiation absorption for each solar thermal absorber at the heating stage, as well as the heat storage effect is shown during the cooling period.

3. Results

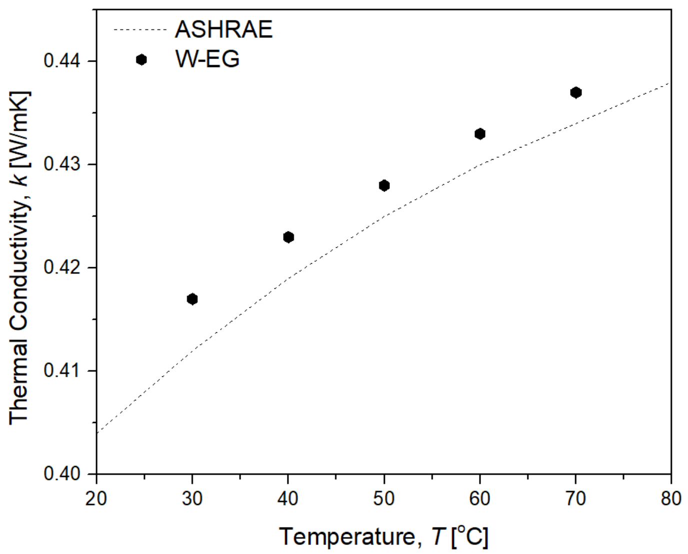
3.1 Thermal Conductivity and Viscosity for TiO_2-SiO_2 Nanofluid Ratio (70:30)

Thermal conductivity and viscosity measurements can be verified through comparison of data between ASHRAE [80] and EG-water (Figure 4). For thermal conductivity measurements, the use of KD2 Pro can be used with 0.9% error verification results while 0.7% of EG-water data mixed with maximum deviation. Researchers such as Reddy and Rao [81] found that the main liquid difference was up to 2.5% compared to ASHRAE [80] during the verification test. Hence, this study can be applied as there is only a small deviation based on previous researcher finding. There is a good similarity with ASHRAE [80] when the viscosity data is compared.

Therefore, for the measurement requirements of thermal conductivity and dynamic viscosity, nanofluid hybrid TiO2-SiO2 with various volume concentrations can be conducted and investigated.



(a) Viscosity for validating



(b) Thermal conductivity for validating

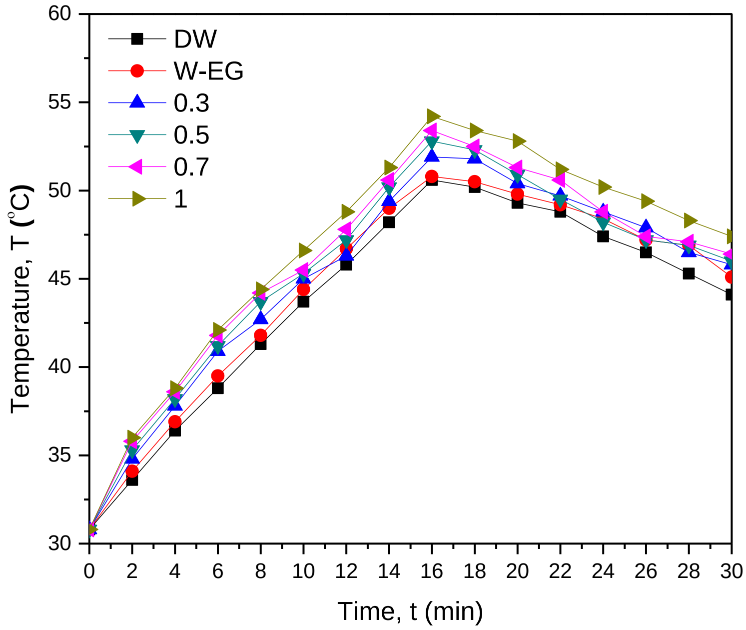
Fig. 4. Validating of Water-EG with ASHRAE [80]

3.2 The Temperature of Absorber Concerning Different Solar Radiation with TiO_2-SiO_2 Nanofluid Ratio (70:30)

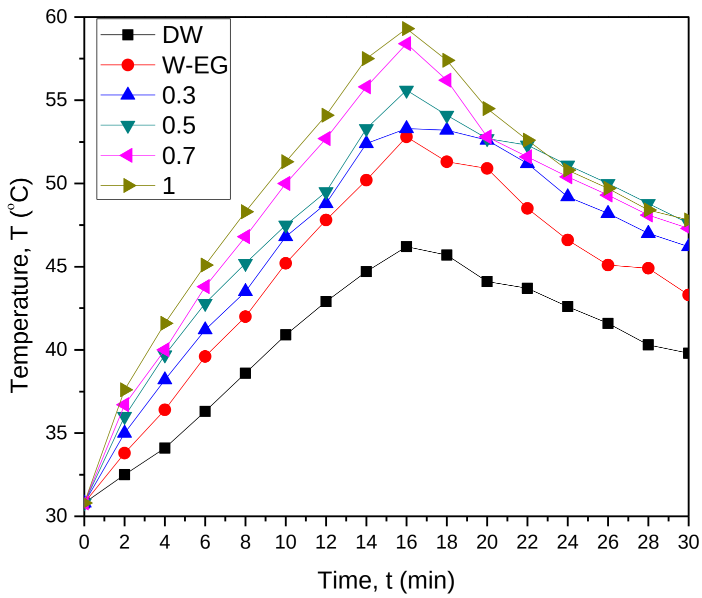
The results presented in Figure 5 shows the behavior of the output temperature of the absorber concerning their different solar radiation. The highest point on each graph indicates the end of the charging process and the beginning of the discharging process. Based on the result, the maximum concentrations of 1.0% is observed to consistently provide higher temperature output as compared to the other three concentrations of nanofluids.

Figure 5(a) shows the maximum temperature achieved within 15 minutes of charging process is 51.9 °C, 52.8 °C, 53.4 °C and 54.2 °C for the concentration of nanofluids 0.3, 0.5, 0.7 and 1.0% respectively for solar radiation of 300 W/m^2. Meanwhile, for solar radiation of 500 W/m^2, the temperature during the heating process increasing until the maximum value within the 15 minutes plotted in Figure 5(b). Besides that, the result shows increasing rapidly for solar radiation 700 W/m^{2,}

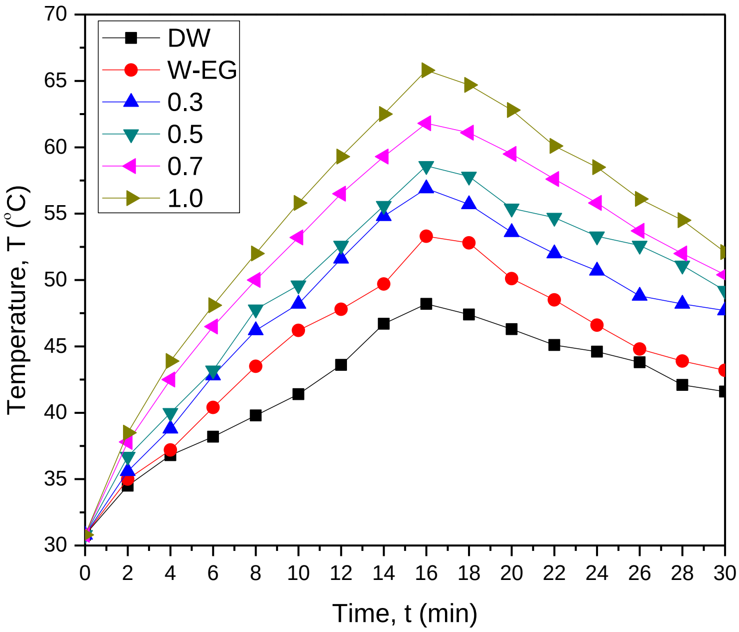
and the maximum temperature achieved 56.9, 58.6, 61.8 and 65.8 °C for the concentration of nanofluids 0.3, 0.5, 0.7 and 1.0% respectively within 15 minutes charging as shown in Figure 5(c). Therefore, it can be concluded that the higher concentrations give ample time to the test tube to transfer the heat and thus increased its temperature during the charging process.



(a) Solar radiation at 300 W/m^2



(b) Solar radiation at 500 W/m^2



(c) Solar radiation at 700 W/m^2

Fig. 5. Temperature output of the absorber based on base fluid and nanofluids

4. Conclusions

Investigation on the effect of mass flow rate to the output temperature of the absorber was performed using the solar simulator to produce three different radiations of 300 W/m^2, 500 W/m^2, and 700 W/m^2. It is observed that higher concentration of nanofluids of 1.0% provided an ample time to receive the heat from test tube led to the increase of output temperature Thermal absorber during cooling down/discharging period shows that higher concentrations of nanofluids prolonged the cooling down/ discharging period. The intensity of solar radiation provides a major contribution to the total heat gain by the thermal absorber.

References

[1] Bamisile, Olusola O., and Mustafa Dagbasi. "Analysis of Serhatkoy Photovoltaic Power Plant and Production over the Years it Application to a Central City in Nigeria (Markurdi)." *International Journal of Engineering Research & Technology (IJERT)* 4, no. 04 (2015): 562-568. https://doi.org/10.17577/IJERTV4IS040751

[2] Bergmann, Ariel, Sergio Colombo, and Nick Hanley. "Rural versus urban preferences for renewable energy developments." *Ecological economics* 65, no. 3 (2008): 616-625. https://doi.org/10.1016/j.ecolecon.2007.08.011

[3] Painuly, Jyoti P. "Barriers to renewable energy penetration; a framework for analysis." *Renewable energy* 24, no. 1 (2001): 73-89. https://doi.org/10.1016/S0960-1481(00)00186-5

[4] Ellabban, Omar, Haitham Abu-Rub, and Frede Blaabjerg. "Renewable energy resources: Current status, future prospects and their enabling technology." *Renewable and Sustainable Energy Reviews* 39 (2014): 748-764. https://doi.org/10.1016/j.rser.2014.07.113

[5] Alrikabi, N. "Kh. MA (2014)." *Renewable Energy Types. Journal of Clean Energy Technologies* 2, no. 1: 61-64. https://doi.org/10.7763/JOCET.2014.V2.92

[6] Suman, Siddharth. "Hybrid nuclear-renewable energy systems: A review." *Journal of Cleaner Production* 181 (2018): 166-177. https://doi.org/10.1016/j.jclepro.2018.01.262

[7] Heras-Saizarbitoria, Iñaki, Lucía Sáez, Erlantz Allur, and Jon Morandeira. "The emergence of renewable energy cooperatives in Spain: A review." *Renewable and Sustainable Energy Reviews* 94 (2018): 1036-1043. https://doi.org/10.1016/j.rser.2018.06.049

[8] Liu, Junxia. "China's renewable energy law and policy: a critical review." *Renewable and Sustainable Energy Reviews* 99 (2019): 212-219. https://doi.org/10.1016/j.rser.2018.10.007

[9] Jenniches, Simon. "Assessing the regional economic impacts of renewable energy sources–A literature review." *Renewable and Sustainable Energy Reviews* 93 (2018): 35-51. https://doi.org/10.1016/j.rser.2018.05.008
[10] Şener, Şerife Elif Can, Julia L. Sharp, and Annick Anctil. "Factors impacting diverging paths of renewable energy: A review." *Renewable and Sustainable Energy Reviews* 81 (2018): 2335-2342. https://doi.org/10.1016/j.rser.2017.06.042
[11] Guo, Shaopeng, Qibin Liu, Jie Sun, and Hongguang Jin. "A review on the utilization of hybrid renewable energy." *Renewable and Sustainable Energy Reviews* 91 (2018): 1121-1147. https://doi.org/10.1016/j.rser.2018.04.105
[12] Shuba, Eyasu Shumbulo, and Demeke Kifle. "Microalgae to biofuels:'Promising'alternative and renewable energy, review." *Renewable and Sustainable Energy Reviews* 81 (2018): 743-755. https://doi.org/10.1016/j.rser.2017.08.042
[13] Khan, Meer AM, Shafiqur Rehman, and Fahad A. Al-Sulaiman. "A hybrid renewable energy system as a potential energy source for water desalination using reverse osmosis: A review." *Renewable and Sustainable Energy Reviews* 97 (2018): 456-477. https://doi.org/10.1016/j.rser.2018.08.049
[14] Picchi, Paolo, Martina van Lierop, Davide Geneletti, and Sven Stremke. "Advancing the relationship between renewable energy and ecosystem services for landscape planning and design: A literature review." *Ecosystem services* 35 (2019): 241-259. https://doi.org/10.1016/j.ecoser.2018.12.010
[15] Rueda-Bayona, Juan Gabriel, Andres Guzmán, Juan José Cabello Eras, Rodolfo Silva-Casarín, Emilio Bastidas-Arteaga, and José Horrillo-Caraballo. "Renewables energies in Colombia and the opportunity for the offshore wind technology." *Journal of Cleaner Production* 220 (2019): 529-543. https://doi.org/10.1016/j.jclepro.2019.02.174
[16] Fekadu, Geleta, and Sudhakar Subudhi. "Renewable energy for liquid desiccants air conditioning system: A review." *Renewable and Sustainable Energy Reviews* 93 (2018): 364-379. https://doi.org/10.1016/j.rser.2018.05.016
[17] Panwar, N. L., S. C. Kaushik, and Surendra Kothari. "Role of renewable energy sources in environmental protection: A review." *Renewable and sustainable energy reviews* 15, no. 3 (2011): 1513-1524. https://doi.org/10.1016/j.rser.2010.11.037
[18] Zakhidov, R. A. "Central Asian countries energy system and role of renewable energy sources." *Applied Solar Energy* 44, no. 3 (2008): 218-223. https://doi.org/10.3103/S0003701X08030201
[19] Wazeer, Adil, Bhaskar Chaturvedi, Shriyash Mohril, Mahipal Singh Sankhla, and Dr Rajeev Kumar. "Gasification-Contributing to the Energy Production Demands." *International Journal of Engineering And Computer Science* 5, no. 12 (2016): 19440-19449. https://doi.org/10.18535/ijecs/v5i12.30
[20] Ravindranath, Nijavalli H., and David Oakley Hall. *Biomass, energy and environment: a developing country perspective from India*. Oxford University Press, 1995.
[21] Jin, Xin, Guiping Lin, Aimen Zeiny, Haichuan Jin, Lizhan Bai, and Dongsheng Wen. "Solar photothermal conversion characteristics of hybrid nanofluids: An experimental and numerical study." *Renewable Energy* 141 (2019): 937-949. https://doi.org/10.1016/j.renene.2019.04.016
[22] Sun, Bin, Yue Zhang, Di Yang, and Hongwei Li. "Experimental study on heat transfer characteristics of hybrid nanofluid impinging jets." *Applied Thermal Engineering* 151 (2019): 556-566. https://doi.org/10.1016/j.applthermaleng.2019.01.111
[23] Huminic, Gabriela, and Angel Huminic. "Heat transfer capability of the hybrid nanofluids for heat transfer applications." *Journal of Molecular Liquids* 272 (2018): 857-870. https://doi.org/10.1016/j.molliq.2018.10.095
[24] Yagnem, Anil Reddy, and S. Venkatachalapathy. "Heat transfer enhancement studies in pool boiling using hybrid nanofluids." *Thermochimica Acta* 672 (2019): 93-100. https://doi.org/10.1016/j.tca.2018.11.014
[25] Moldoveanu, Georgiana Madalina, and Alina Adriana Minea. "Specific heat experimental tests of simple and hybrid oxide-water nanofluids: proposing new correlation." *Journal of Molecular Liquids* 279 (2019): 299-305. https://doi.org/10.1016/j.molliq.2019.01.137
[26] Kaska, Sheren A., Rafeq A. Khalefa, and Adnan M. Hussein. "Hybrid nanofluid to enhance heat transfer under turbulent flow in a flat tube." *Case Studies in Thermal Engineering* 13 (2019): 100398. https://doi.org/10.1016/j.csite.2019.100398
[27] Manjunatha, S., B. Ammani Kuttan, S. Jayanthi, Ali Chamkha, and B. J. Gireesha. "Heat transfer enhancement in the boundary layer flow of hybrid nanofluids due to variable viscosity and natural convection." *Heliyon* 5, no. 4 (2019): e01469. https://doi.org/10.1016/j.heliyon.2019.e01469
[28] Aparna, Z., Monisha Michael, S. K. Pabi, and S. Ghosh. "Thermal conductivity of aqueous $Al2O3/Ag$ hybrid nanofluid at different temperatures and volume concentrations: an experimental investigation and development of new correlation function." *Powder Technology* 343 (2019): 714-722. https://doi.org/10.1016/j.powtec.2018.11.096

[29] Waini, Iskandar, Anuar Ishak, and Ioan Pop. "Unsteady flow and heat transfer past a stretching/shrinking sheet in a hybrid nanofluid." *International Journal of Heat and Mass Transfer* 136 (2019): 288-297. https://doi.org/10.1016/j.ijheatmasstransfer.2019.02.101

[30] Venkataraman, B., and D. Elango. "Renewable Energy Sources." *Hindustan College of Engineering, Padur, India* (1998).

[31] Thirugnanasambandam, Mirunalini, Selvarasan Iniyan, and Ranko Goic. "A review of solar thermal technologies." *Renewable and sustainable energy reviews* 14, no. 1 (2010): 312-322. https://doi.org/10.1016/j.rser.2009.07.014

[32] Koroneos, Christopher J., and Evanthia A. Nanaki. "Life cycle environmental impact assessment of a solar water heater." *Journal of Cleaner Production* 37 (2012): 154-161. https://doi.org/10.1016/j.jclepro.2012.07.001

[33] Ho, C. D., and T. C. Chen. "The recycle effect on the collector efficiency improvement of double-pass sheet-and-tube solar water heaters with external recycle." *Renewable Energy* 31, no. 7 (2006): 953-970. https://doi.org/10.1016/j.renene.2005.05.016

[34] Al-Madani, Hussain. "The performance of a cylindrical solar water heater." *Renewable Energy* 31, no. 11 (2006): 1751-1763. https://doi.org/10.1016/j.renene.2005.09.010

[35] Fikri, Mohd Amiruddin, Fatin Fatihah Asri, Wan Mohd Faizal, Hasyiya Karimah Adli, Rizalman Mamat, W. H. Azmi, A. I. Ramadhan, and Talal Yusaf. "Effects of heat transfer based water for three square multilayer absorber solar collector." In *IOP Conference Series: Materials Science and Engineering*, vol. 788, no. 1, p. 012078. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/788/1/012078

[36] Zhai, X. Q., R. Z. Wang, Y. J. Dai, J. Y. Wu, and Q. Ma. "Experience on integration of solar thermal technologies with green buildings." *Renewable Energy* 33, no. 8 (2008): 1904-1910. https://doi.org/10.1016/j.renene.2007.09.027

[37] Otanicar, Todd P., Patrick E. Phelan, Ravi S. Prasher, Gary Rosengarten, and Robert A. Taylor. "Nanofluid-based direct absorption solar collector." *Journal of renewable and sustainable energy* 2, no. 3 (2010): 033102. https://doi.org/10.1063/1.3429737

[38] Okujagu, C. U., and S. K. Adjepong. "Performance of a simple flat plate solar collector at an equatorial location." *Solar & wind technology* 6, no. 3 (1989): 283-289. https://doi.org/10.1016/0741-983X(89)90081-7

[39] Choi, Stephen US, and Jeffrey A. Eastman. *Enhancing thermal conductivity of fluids with nanoparticles*. No. ANL/MSD/CP-84938; CONF-951135-29. Argonne National Lab., IL (United States), 1995.

[40] Masuda, Hidetoshi, Akira Ebata, K. Teramae, and N. Hishiunma. "conductivity and viscosity of liquid by dispersed ultra-fine particles (dispersion of Al2O3, SiO2, and TiO2 ultra-fine particles)." *Alteration of Thermal, Netsu Bussei (Japan)* 7, no. 4 (1993). https://doi.org/10.2963/jjtp.7.227

[41] Azmi, W. H., K. V. Sharma, Rizalman Mamat, and Shahrani Anuar. "Nanofluid properties for forced convection heat transfer: An overview." *Journal of Mechanical Engineering and Sciences* 4 (2013): 397-408. https://doi.org/10.15282/jmes.4.2013.4.0037

[42] Abu-Nada, Eiyad, and Ali J. Chamkha. "Effect of nanofluid variable properties on natural convection in enclosures filled with a CuO–EG–water nanofluid." *International Journal of Thermal Sciences* 49, no. 12 (2010): 2339-2352. https://doi.org/10.1016/j.ijthermalsci.2009.09.002

[43] Sarkar, Jahar, Pradyumna Ghosh, and Arjumand Adil. "A review on hybrid nanofluids: recent research, development and applications." *Renewable and Sustainable Energy Reviews* 43 (2015): 164-177. https://doi.org/10.1016/j.rser.2014.11.023

[44] Yilmaz, Fatih. "Thermodynamic performance evaluation of a novel solar energy based multigeneration system." *Applied Thermal Engineering* 143 (2018): 429-437. https://doi.org/10.1016/j.applthermaleng.2018.07.125

[45] Khaliq, Abdul, Esmail MA Mokheimer, and Mohammed Yaqub. "Thermodynamic investigations on a novel solar powered trigeneration energy system." *Energy Conversion and Management* 188 (2019): 398-413. https://doi.org/10.1016/j.enconman.2019.03.026

[46] Fathabadi, Hassan. "Solar energy harvesting in buildings using a proposed novel electrochemical device as an alternative to PV modules." *Renewable Energy* 133 (2019): 118-125. https://doi.org/10.1016/j.renene.2018.10.010

[47] El-Emam, Rami S., and Ibrahim Dincer. "Investigation and assessment of a novel solar-driven integrated energy system." *Energy Conversion and Management* 158 (2018): 246-255. https://doi.org/10.1016/j.enconman.2017.12.062

[48] Karapekmez, Aras, and Ibrahim Dincer. "Thermodynamic analysis of a novel solar and geothermal based combined energy system for hydrogen production." *International Journal of Hydrogen Energy* 45, no. 9 (2020): 5608-5628.

[49] Mehrpooya, Mehdi, Bahram Ghorbani, and Mehrdad Moradi. "A novel MCFC hybrid power generation process using solar parabolic dish thermal energy." *International Journal of Hydrogen Energy* 44, no. 16 (2019): 8548-8565. https://doi.org/10.1016/j.ijhydene.2018.12.014

[50] Yilmaz, Fatih, Murat Ozturk, and Resat Selbas. "Energy and exergy performance assessment of a novel solar-based integrated system with hydrogen production." *International Journal of Hydrogen Energy* 44, no. 34 (2019): 18732-18743. https://doi.org/10.1016/j.ijhydene.2018.10.118
[51] Fernández, R., C. Ortiz, R. Chacartegui, J. M. Valverde, and J. A. Becerra. "Dispatchability of solar photovoltaics from thermochemical energy storage." *Energy Conversion and Management* 191 (2019): 237-246. https://doi.org/10.1016/j.enconman.2019.03.074
[52] Jia, Hao, Xiaomei Cheng, Jingjing Zhu, Zhaoling Li, and Jiansheng Guo. "Mathematical and experimental analysis on solar thermal energy harvesting performance of the textile-based solar thermal energy collector." *Renewable energy* 129 (2018): 553-560. https://doi.org/10.1016/j.renene.2018.05.097
[53] Khan, M. Ryyan, Enas Sakr, Xingshu Sun, Peter Bermel, and Muhammad A. Alam. "Ground sculpting to enhance energy yield of vertical bifacial solar farms." *Applied Energy* 241 (2019): 592-598. https://doi.org/10.1016/j.apenergy.2019.01.168
[54] Şevik, Seyfi, Mustafa Aktaş, Ekin Can Dolgun, Erhan Arslan, and Azim Doğuş Tuncer. "Performance analysis of solar and solar-infrared dryer of mint and apple slices using energy-exergy methodology." *Solar Energy* 180 (2019): 537-549. https://doi.org/10.1016/j.solener.2019.01.049
[55] Mosaffa, A. H., Z. Ghaffarpour, and L. Garousi Farshi. "Thermoeconomic assessment of a novel integrated CHP system incorporating solar energy based biogas-steam reformer with methanol and hydrogen production." *Solar Energy* 178 (2019): 1-16. https://doi.org/10.1016/j.solener.2018.12.011
[56] Sundar, L. Syam, P. Bhramara, NT Ravi Kumar, Manoj K. Singh, and Antonio CM Sousa. "Experimental heat transfer, friction factor and effectiveness analysis of Fe3O4 nanofluid flow in a horizontal plain tube with return bend and wire coil inserts." *International Journal of Heat and Mass Transfer* 109 (2017): 440-453. https://doi.org/10.1016/j.ijheatmasstransfer.2017.02.022
[57] Azmi, W. H., K. Abdul Hamid, N. A. Usri, Rizalman Mamat, and M. S. Mohamad. "Heat transfer and friction factor of water and ethylene glycol mixture based TiO2 and Al2O3 nanofluids under turbulent flow." *International Communications in Heat and Mass Transfer* 76 (2016): 24-32. https://doi.org/10.1016/j.icheatmasstransfer.2016.05.010
[58] Hamid, K. Abdul, W. H. Azmi, M. F. Nabil, and Rizalman Mamat. "Experimental investigation of nanoparticle mixture ratios on TiO2–SiO2 nanofluids heat transfer performance under turbulent flow." *International Journal of Heat and Mass Transfer* 118 (2018): 617-627. https://doi.org/10.1016/j.ijheatmasstransfer.2017.11.036
[59] Nabil, M. F., W. H. Azmi, K. Abdul Hamid, Rizalman Mamat, and Ftwi Y. Hagos. "An experimental study on the thermal conductivity and dynamic viscosity of TiO2-SiO2 nanofluids in water: ethylene glycol mixture." *International Communications in Heat and Mass Transfer* 86 (2017): 181-189. https://doi.org/10.1016/j.icheatmasstransfer.2017.05.024
[60] Hamid, K. Abdul, W. H. Azmi, Rizalman Mamat, and K. V. Sharma. "Heat transfer performance of TiO2–SiO2 nanofluids in a tube with wire coil inserts." *Applied Thermal Engineering* 152 (2019): 275-286. https://doi.org/10.1016/j.applthermaleng.2019.02.083
[61] Azmi, W. H., K. Abdul Hamid, Rizalman Mamat, K. V. Sharma, and M. S. Mohamad. "Effects of working temperature on thermo-physical properties and forced convection heat transfer of TiO2 nanofluids in water–Ethylene glycol mixture." *Applied Thermal Engineering* 106 (2016): 1190-1199. https://doi.org/10.1016/j.applthermaleng.2016.06.106
[62] Ramadhan, A. I., W. H. Azmi, R. Mamat, M. Mazlan, "A new correlation of thermal-properties of tri-hybrid nanoparticles in water-ethylene glycol mixture", Technology Reports of Kansai University, 62(2) (2020): 1151-1160.
[63] Ramadhan, A. I., W. H. Azmi, R. Mamat, and K. A. Hamid. "Experimental and numerical study of heat transfer and friction factor of plain tube with hybrid nanofluids." *Case Studies in Thermal Engineering* 22 (2020): 100782. https://doi.org/10.1016/j.csite.2020.100782
[64] Ramadhan, A. I., W. H. Azmi, and R. Mamat. "Heat transfer characteristics of car radiator using tri-hybrid nanocoolant." In *IOP Conference Series: Materials Science and Engineering*, vol. 863, no. 1, p. 012054. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/863/1/012054
[65] Saeedinia, M., M. A. Akhavan-Behabadi, and M. Nasr. "Experimental study on heat transfer and pressure drop of nanofluid flow in a horizontal coiled wire inserted tube under constant heat flux." Experimental Thermal and Fluid Science 36 (2012): 158-168. https://doi.org/10.1016/j.expthermflusci.2011.09.009
[66] Ramadhan, A. I., W. H. Azmi, R. Mamat, K. A. Hamid, and S. Norsakinah. "Investigation on stability of tri-hybrid nanofluids in water-ethylene glycol mixture." In *IOP Conference Series: Materials Science and Engineering*, vol. 469, no. 1, p. 012068. IOP Publishing, 2019. https://doi.org/10.1088/1757-899X/469/1/012068
[67] Baghbanzadeh, Mohammadali, Alimorad Rashidi, Davood Rashtchian, Roghayeh Lotfi, and Azadeh Amrollahi. "Synthesis of spherical silica/multiwall carbon nanotubes hybrid nanostructures and investigation of thermal

conductivity of related nanofluids." *Thermochimica acta* 549 (2012): 87-94. https://doi.org/10.1016/j.tca.2012.09.006

[68] Hamid, K. Abdul, W. H. Azmi, M. F. Nabil, Rizalman Mamat, and K. V. Sharma. "Experimental investigation of thermal conductivity and dynamic viscosity on nanoparticle mixture ratios of TiO2-SiO2 nanofluids." *International Journal of Heat and Mass Transfer* 116 (2018): 1143-1152. https://doi.org/10.1016/j.ijheatmasstransfer.2017.09.087

[69] Azmi, W. H., K. V. Sharma, P. K. Sarma, Rizalman Mamat, and G. Najafi. "Heat transfer and friction factor of water based TiO2 and SiO2 nanofluids under turbulent flow in a tube." *International Communications in Heat and Mass Transfer* 59 (2014): 30-38. https://doi.org/10.1016/j.icheatmasstransfer.2014.10.007

[70] Mohamad, M., and W. Wan. "Heat transfer performance Of Tio2–SiO2 nanofluid in water-ethylene glycol mixture." *J Mech Eng* 5 (2018): 39-48.

[71] Das, Sarit K., Nandy Putra, and Wilfried Roetzel. "Pool boiling characteristics of nano-fluids." *International journal of heat and mass transfer* 46, no. 5 (2003): 851-862. https://doi.org/10.1016/S0017-9310(02)00348-4

[72] Ding, Yulong. "Hajar Alias, Dongsheng Wen, Richard A. Williams." *Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids). International Journal of Heat and Mass Transfer* 49, no. 1-2 (2006): 240-250. https://doi.org/10.1016/j.ijheatmasstransfer.2005.07.009

[73] Ding, Yulong, Haisheng Chen, Liang Wang, Chane-Yuan Yang, Yurong He, Wei Yang, Wai Peng Lee, Lingling Zhang, and Ran Huo. "Heat transfer intensification using nanofluids." *KONA Powder and Particle Journal* 25 (2007): 23-38. https://doi.org/10.14356/kona.2007006

[74] Khdher, AbdolBaqi Mohammed, Nor Azwadi Che Sidik, Rizalman Mamat, and Wan Azmi Wan Hamzah. "Experimental and numerical study of thermo-hydraulic performance of circumferentially ribbed tube with Al2O3 nanofluid." *International Communications in Heat and Mass Transfer* 69 (2015): 34-40. https://doi.org/10.1016/j.icheatmasstransfer.2015.10.003

[75] Wen, Dongsheng, and Yulong Ding. "Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions." *International journal of heat and mass transfer* 47, no. 24 (2004): 5181-5188. https://doi.org/10.1016/j.ijheatmasstransfer.2004.07.012

[76] Mintsa, Honorine Angue, Gilles Roy, Cong Tam Nguyen, and Dominique Doucet. "New temperature dependent thermal conductivity data for water-based nanofluids." *International journal of thermal sciences* 48, no. 2 (2009): 363-371. https://doi.org/10.1016/j.ijthermalsci.2008.03.009

[77] Pak, Bock Choon, and Young I. Cho. "Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles." *Experimental Heat Transfer an International Journal* 11, no. 2 (1998): 151-170. https://doi.org/10.1080/08916159808946559

[78] Namburu, P. K., D. P. Kulkarni, A. Dandekar, and D. K. Das. "Experimental investigation of viscosity and specific heat of silicon dioxide nanofluids." *Micro & Nano Letters* 2, no. 3 (2007): 67-71. https://doi.org/10.1049/mnl:20070037

[79] Yu, Wei, Huaqing Xie, Lifei Chen, and Yang Li. "Investigation of thermal conductivity and viscosity of ethylene glycol based ZnO nanofluid." *Thermochimica Acta* 491, no. 1-2 (2009): 92-96. https://doi.org/10.1016/j.tca.2009.03.007

[80] Handbook—Fundamentals, A. S. H. R. A. E., and S. I. Edition. "chapter 21-22." *American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Ga, USA* (2009).

[81] Reddy, M. Chandra Sekhara, and V. Vasudeva Rao. "Experimental studies on thermal conductivity of blends of ethylene glycol-water-based TiO2 nanofluids." *International communications in heat and mass transfer* 46 (2013): 31-36. https://doi.org/10.1016/j.icheatmasstransfer.2013.05.009